LCA Case Studies

Life Cycle Assessment through On-Line Database Linked with Various Enterprise Database Systems

Jeong Min Moon[1], Ki Suk Chung[1], Jong Hwan Eun[2] and Jong Shik Chung[1,2*]

[1] Department of Chemical Engineering, Pohang University of Science and Technology, San 31, Hyoja-dong, Namgu, Pohang 790-784, Korea
[2] School of Environmental Engineering, Pohang University of Science and Technology, San 31, Hyoja-dong, Namgu, Pohang 790-784, Korea

* Corresponding author (jsc@postech.ac.kr)

DOI: http://dx.doi.org/10.1065/lca2003.06.116

Abstract

Goal, Scope and Background. Performing a life cycle assessment (LCA) has been a rather resource and time-consuming business. The method of data collection may be problematic, and the quality of the final results can be influenced by the reliability of the data. Therefore, it is helpful to utilize an on-line data gathering system to save time and to improve the reliability of the collected raw data.

Main Features. We have developed an LCA software package for a steel company. The software consists of two major parts: an LCA tool kit and an interface program. The LCA tool kit is a user interface for handling an LCA database server. It has powerful functions to execute systematic analysis, not only for the amount of energy and raw materials, but also for the volume of pollutants generated by each component. The latter is an interface program between a data handling system and an on-line data gathering system. This interface program is linked with three enterprise database systems, such as enterprise resource planning (ERP), an environmental management system (EMS) and an energy server system (ESS). In this study, we compared three different ways of performing LCA. Two of them are on-line methods, and another is manual.

Results and Discussion. Among the three methods, the best method was on-line LCA linked with ERP, EMS and ESS. Case studies in steel works have shown that the current method is superior to manual data gathering in terms of time and cost (man-month) savings, data reliability and other applications. Results of life cycle inventory and life cycle impact assessment for steel products have shown monthly fluctuations due to fuel usage ratio, which have not been detected before using manual data gathering.

Conclusions. An LCA can be performed quickly, if one is to employ the on-line data gathering system we have developed. The system consists of an LCA software package including the interface program and LCA tool kit, and the enterprise database systems. Case studies for LCA with the on-line system have shown superior performance to that carried out using the manual data entry method.

Recommendations and Perspective. This system enables an enterprise to take Type III and conduct benchmarking to other companies or societies within a short time. Also, combining this tool with an environmental performance evaluation or accounting system can allow one to achieve a more progressive environmental management.

Keywords: Client/server; energy server system; enterprise database system; environmental management system; enterprise resource planning; integrated interface; life cycle assessment (LCA); LCA software package; on-line data gathering; steel product

1 Goal, Scope and Background

Life cycle assessment (LCA) is defined as the "compilation and evaluation of the inputs, outputs and potential environmental impacts of a product system throughout its life cycle" (ISO 1997, CML 2001). The life cycle of the product is defined as the system consisting of models for technological activities in the various stages of the products: from resource extractions for the products, through material productions, and those processes and product usages for fulfillment of its function, to waste treatments for the discarded products (ISO 1997, Klöpffer 1997). In the case of an intermediate product such as steel, if necessary, its life cycle is limited as being 'cradle to gate.' Besides the LCA research for the products, process, service or policy can also be an object for the LCA research, if this has a holistic cradle-to-grave basis (Heijungs and Guinée 1995). Thus, the LCA studies can be performed for a whole range of different decision-making situations from mere internal use to public comparative use. These are generally five different types of situations, namely: company-internal innovation, sector-driven innovation, strategic planning, comparison, and comparative assertion disclosed to the public (CML 2001).

Executing an LCA is a fairly resource and time-consuming process, so that gathering raw data is therefore difficult. Moreover, the reliability of data may affect the quality of the final results. Because of these reasons, we need to introduce other methods to save time and resources, so that we can improve the performance for conducting an LCA. This can be realized by introducing an on-line data gathering system. We can also increase the reliability of the collected raw data by using data sources, which are verified through enterprise database systems.

Nowadays, most companies are employing enterprise resource planning (ERP) systems in the core of management information systems. It is possible to realize the on-line data gathering systems utilizing these ERP systems. There are also some research groups who have attempted to develop such kind of on-line system. Recently, three different methods for the on-line systems have been proposed. These deal with the interaction between the LCA software tool and the ERP system: interfacing of the external LCA software linked with the ERP system, adapting the complete LCA functionality into the ERP system and adding the LCIA part out of the

LCA into the ERP system, while at the same time connecting the remaining parts for the LCA software with the ERP system (Januschkowetz et al. 2000). Posch (Posch 2001) has reported on a tool namely STABIS, which enables industry to achieve holistic, knowledge-based environmental management. When the STABIS is operated, data is collected in the existing ERP from specific organizations. In the event that the data is not accumulated in the ERP system, it has to be provided by other additional means, e.g. manual dataentrys or stand-alone applications. Data redundancy should be avoided, because they generally employ different database systems within the same organization. The STABIS does not seem to be a professional tool to execute an exact LCA, but it is a simple tool to conduct the International Standardization Organization (ISO) 14000 series. In 1998, an LCA evaluation software (LCA SUPPORT) has been developed by NEC Co. (NEC 2001). The software is incorporated with the development of environmentally-sound products. In 2000, the NEC began to implement an on-line system. The main purpose of the system integration is gathering environmental information and constructing database for packaging materials. This is a database system for green procurement and the system is receiving the environmental data from vendors' information through the Web. However, the work has not yet been performed fully for the on-line data gathering system.

In this study, we will show how to construct a new on-line database system by integrating LCA software packages with various enterprise database systems such as enterprise resource planning (ERP), an environmental management system (EMS) and energy server system (ESS). Subsequently, we will execute an LCA utilizing the newly developed system to demonstrate the performance of the system. At the first stage of this work, we will demonstrate the methods for the interface and the pros and cons of the relatively old methods. Subsequently, in the following section, we will apply the newly developed LCA on-line data gathering and in-situ performing system on steel products.

2 LCA Applications

2.1 Environmental management and LCA

The paradigm of environmental management is shifting from point source control, through non-point source control, to sustainable development. Environmental management requires an interdisciplinary study between science, engineering, economy and management. It should also be an integrated system employing vertical and horizontal management. Vertical management includes the stages such as purchasing, production, product development, accounting, marketing, and so on. The horizontal part involves the stages of resource extraction, transportation, product use, recycling, the disposal of a product, etc. ISO has developed generalized global standards that can be used by organizations to enhance their environmental performance. These standards have been grouped together under the ISO 14000 banner of environmental management (ISO 1997, Ross and Evans 2002). The 14000 series of standards addresses the following aspects of environmental management:

- Environmental Management Systems (EMS, ISO 14001)
- Environmental Auditing & Related Investigations (EA & RI, ISO 14010s)
- Environmental Labels and Declarations (EL & ED, ISO 14020s)
- Environmental Performance Evaluation (EPE, ISO 14030s)
- Life Cycle Assessment (LCA, ISO 14040s)

Among these standards, LCA can be the basis of an environmental management model, because it provides basic data to other environmental, analytical tools. LCA framework is described by three standards in the ISO 14040 series. Those are ISO 14041: Goal and Scope Definition and Inventory Analysis (ISO 1998), ISO 14042: Life Cycle Impact Assessment (ISO 1999) and ISO 14043: Life Cycle Interpretation (ISO 2000).

2.2 Various enterprise database systems in a company

Enterprise resource planning (ERP) is a new system for enterprise management that was developed from material requirement planning (MRP) in the 1970s. It is similar to the management information system (MIS) of the 1960s or strategic information system (SIS) in the 1980s. In the 1990s, ERP takes the lead in the business systems. An ERP system is an integrated information system that efficiently manages all the human and physical resources used for an enterprise's business activities, and thus enhances its competitiveness. As a kind of database system, it includes application modules for the accounting, finance, human resources, procurement, production, etc. However, due to the lack of information, an efficient business management database system is not sufficient with the ERP system alone. Extended ERP, containing such features as supply chain management (SCM) and customer relationship management (CRM), is on the rise. Strategic enterprise management (SEM), including such features as a balanced score card (BSC), activity based management (ABM), value based management (VBM), etc., is also needed (KERP21 2002).

Beside the ERP system, some enterprises have an environmental management system (EMS), an energy server system (ESS), and a legacy system. EMS is an indispensable system for environmental management. Data for emissions to air, water and soil belongs to EMS. ESS controls much utility data for water, steam, energy, and electricity, that are necessary for the production of a product. And it also includes some data for materials and products. The legacy system has operated on the circumstance of information technology related to manufacturing during the last few decades. In this system, a lot of data such as materials, products, energy, wastes, emissions, operation conditions, etc., which are connected with manufacturing processes in a factory, are included. Since the legacy system is an old database system, it is necessary to modernize it by adding Web-enable technology and an object-based solution. In fact, most data in ERP, EMS and ESS is transferred from the legacy system after being converted into a proper data format for each system. For constructing an on-line LCA database, the legacy system can provide additional data that is lacking in the three systems.

Because the management information of an enterprise is managed in a little different way for each database system, interface with these database systems should be integrated

for on-line data gathering to perform LCA. On-line data collection through these enterprise database systems enables LCA practicians to save time and cost in conducting LCA.

2.3 LCA software of client/server type

Up to recently, LCA has gained general acceptance as an environmental analysis method for a product. As the necessity of LCA increases, the development of software tools and databases for performing LCA is also on the increase. From the U.S., Europe and Asia, more than 40 software tools are identified. Among them, a few famous software tools are SimaPro, TEAM, GaBi, LCAiT, and so forth. Most LCA tools are of a stand-alone type. Stand-alone LCA software (S/W) requires much time and many human resources to collect data and perform an LCA. Development of the LCA software of client/server (C/S) type can solve such problems by storing LCA data automatically in a database server through on-line data gathering. SimaPro and TEAM were of the stand-alone type in the beginning, but they have now been upgraded to a C/S version. However, it is difficult for the tools to be applied directly to link with enterprise database systems in a company, because they have a different database structure and a low flexibility to access to process information of a company.

In this study, we developed an LCA software package to compute LCA by C/S and to realize linkages with various enterprise database systems (Suh et al. 2000, POSTECH 2002). In the next section, we discuss how to interface LCA S/W package with those systems efficiently.

3 Methods: Integrated Interface and LCA Database Server

3.1 Interface methods between LCA S/W and enterprise database systems

As we have mentioned above, three different interface methods were suggested concerning how ERP and LCA S/W could be combined (Januschkowetz et al. 2000). According to their research, they nominated the third method as the best one. Using this third method, the data collection and inventory analysis are performed in the ERP and then exported to an LCA S/W for impact assessment. It therefore has flexibility in reporting life cycle impact analysis and an advantage of easy maintenance for the raw data in the ERP. However, it is impossible for clients to perform LCA freely with the personal computers on the desk for other purposes. It is also difficult for us to manage the inventory data for various data formats, because the results of life cycle inventory (LCI) analysis exist within the boundary of the ERP system. For these reasons, we selected the first interface method as an alternative method to improve the weak points in the third one.

There are many advantages to the first method in the user sites. It enables LCA practitioners to execute an LCA either on an on-line or off-line basis. It also has higher flexibility to change the format of data in LCA performance as it is independent of the ERP release cycle. However, in order to interface LCA S/W with the ERP system, the ERP system should contain all the environmental data necessary for the LCA execution. Commercial ERP packages do not usually deal with environmental data, especially that concerning airborne or waterborne emissions. Most companies have environmental data in the environmental management system (EMS). In the case of our target company, utility data such as energy, electricity, steam, water, etc. are usually controlled by the energy server system (ESS). Therefore, we need to interface LCA software to various types of enterprise database systems; in this study, for example, the three systems of ERP, EMS and ESS are utilized for on-line data collection (integrated interface method). In order to have an easy controlling of the data transfer from different database systems, we set up categorization of the data according to the data field. In this study, for example, we set up four category fields of material, product, emission, and utility including energy. Substances such as CO_2, NO_x, dioxin, BOD, suspended solids, etc. belong to the category of the emission field and those such as heavy fuel oil, LNG, LPG, steam, blast air, etc. belong to the category of the utility field. The raw data in each database system is classified according to the category, and transferred only to the pre-assigned category. However, as noticed in **Table 1**, the integrated interface method that we selected has weak points in the inconsistency of data collection. It was impossible to transfer the

Table 1: Three types of interface methods for the on-line data gathering: Strengths and weaknesses

Type	Strengths	Weaknesses
Manual entry method	Collection of all types of trivial data Distinct judgment for erroneous or inconsistent data	Time and cost consuming method Low reliability in data collection Narrow use over departments/sections Slow response for change to perform an LCA
ERP only interface method	Time and cost saving method Improvement of data reliability Excessive data can be avoided Broad range of use over departments/sections Consistent data collection Instant response for change to conduct an LCA	Supplementary work due to construction of environmental module in ERP system Low specialty of raw data Low flexibility of data handling
Integrated interface method (ERP/EMS/ESS)	Time and cost saving method Improvement of data reliability Excessive data can be avoided Broad range of use over departments/sections Instant response for change to conduct an LCA High specialty of raw data Ease of data control according to the fields (material, product, emission, utility)	Inconsistent data collection (Divergence of data sources) Different data format in each system

raw data in the enterprise database system directly into the data category in LCA, because there is no one-to-one correspondence and the unit and data collection period are different between the data in the LCA and that in the enterprise database systems. We solved these problems by adopting a method of integrated interfacing with data standardization. For example, the mass of an emission that will be stored in the LCA database server (LCA DB) can be transferred from the raw data in the database systems after we set a formula with a proper unit standardization to combine (actually to multiply) the concentration in one database system with the flow rate in another (or the same) database system. When the data in the database system has shorter collection periods than those in the LCA DB, we take an average value before the data are transferred into the LCA DB. For data that have longer collection periods, we take the former data in the database system after multiplying the ratio of the collection period in the LCA DB to that in the database system. For example, in the case of air emissions such as particulates, the collection period is occasionally over 5 times a day. And we take the average value of particulates during one month for LCA. In the case of some wastes such as waste cake from cold rolled mill, the collection period is over 6 months. Therefore, if the collection period in LCA DB is one month, the value of waste cake is taken in the basis of the former data from the EMS after multiplying it by the above ratio. In Table 1, the on-line interfacing type of the present integrated interface method is compared with the type of the ERP interface alone, together with the manual entry method.

3.2 Analysis of man-month during LCA execution in iron & steel works

We analyzed the manpower for three types of data interface methods during the execution of LCA and the results are shown in Table 2 –6. Manpower is calculated as man-month (M/M) consumed to conduct LCA for steel products in the steel company having two iron & steel works. One man-month is equal to the amount of labor that one person works during a month on the basis of an 8-hour day, a 5-day week and a 20-day month. The values of man-month in Table 2 – 6 are actually measured or estimated on the basis of LCA projects accomplished during the last three years. For the calculation of M/M, data that belongs only to the in-company process was collected and evaluated. In the case of the upstream data, we used the database that had already been collected during the past LCA works, and therefore they were exempted for the calculation of M/M in the present study.

Table 2 shows the results of man-months consumed to perform LCAs by the manual entry method for steel products. The parentheses in the table represent the amount of work more in detail. For example, '1 worker per 110 unit processes-1 day' in the sixth row represents that it takes 1 day for one person to collect data for LCA of the one unit process using a questionnaire. In all, there are 110 unit processes in the iron & steel works of two sites and LCA works over 40 steel products were carried out in this study. Total M/M consumed to conduct LCAs manually through four phases (goal & scope definition, life cycle inventory analysis, life cycle impact assessment and life cycle interpretation) reaches as much

Table 2: The calculation of M/M consumed to conduct LCAs manually [a]

LCA Phases	Description	M/M
Goal & scope definition	Goal of the study (2 workers and 3 LCA experts – 1 day)	0.250
	Scope of the study (2 workers and 3 LCA experts – 5 days)	1.250
Life cycle inventory analysis	Survey of process trees and data lists (23 workers [b] and 2 LCA experts – 1 day)	1.250
	Drawing of process trees and preparation of questionnaires (3 LCA experts – 10 days)	1.500
	Data collection using questionnaires (1 worker per 110 unit processes – 1 day)	5.500
	Validation of collected data (2 LCA experts – 2 hours per unit process)	2.750
	Confirmation of revised data (1 worker per 110 unit processes – 2 hours)	1.375
	Completion of missing data by calculation/literature survey (1 LCA expert –1 hour per 110 unit processes)	0.688
	Application of LCA methodology such as allocation (2 workers and 3 LCA experts – 5 days)	1.250
	Conversion of data format and insertion data to LCA S/W (1 LCA expert – 2 days)	0.100
	LCI analysis and review (2 LCA experts – 5 days)	0.500
Life cycle impact assessment	Selection of impact assessment method and impact factors (3 LCA experts – 5 days)	0.750
	Life cycle impact assessment (1 LCA experts – 1 day)	0.050
Life cycle interpretation	Selection of interpretation method and its execution (3 LCA experts – 5 days)	0.750
Total (M/M)		**17.963**

[a] The computation of M/M for LCA work was attained after the LCA S/W (prototype) of client/server type was developed.
[b] 23 workers consist of 1 person per 14 departments in A steel works and 1 person per 9 departments in B steel works.

Table 3: LCA performance through interface between LCA S/W package and ERP system alone

LCA and interface	Description	M/M
LCA S/W revision	Analysis of ERP system (2 LCA experts, 3 workers and 1 programmer – 5 days)	1.500
	Modification of LCA S/W (2 LCA experts –10 days; 2 programmers – 20 days)	3.000
Interface program	Completion of mapping table and process trees (2 LCA experts – 10 days; 3 workers – 2 days; 1 programmer – 5 days)	1.550
	Development of interface program and execution of query sentences for interface (1 LCA expert and 1 worker – 3 days; 1 programmer – 20 days)	1.300
	Insertion of environmental module in ERP (1 LCA expert, 1 worker and 2 programmer – 20 days)	4.000
	Cross check between on-line data and off-line data (2 LCA experts – 30 days; 2 workers – 5 day; 1 programmer – 20 days)	4.500
	Construction of LCA database server and test (2 LCA experts, 1 worker and 1 programmer – 10 days)	2.000
Life cycle assessment	LCA execution	0.306 [a]
Total (M/M)		**18.156**

[a] The value of M/M comes from the result of the fourth column in Table 5.

Table 4: LCA performance through integrated interface between LCA S/W package and ERP/EMS/ESS

LCA and interface	Description	M/M
LCA S/W revision	Analysis of enterprise database systems (ERP/EMS/ESS) (2 LCA experts, 5 workers and 1 programmer – 5 days)	2.000
	Modification of LCA S/W (2 LCA experts – 10 days; 2 programmers – 20 days)	3.000
Interface program	Completion of mapping table and process trees (2 LCA experts – 10 days; 5 workers – 2 day; 1 programmer – 5 days)	1.750
	Development of interface program and execution of query sentences for interface (1 LCA expert and 1 worker – 3 days; 1 programmer – 30 days)	1.800
	Cross check between on-line data and off-line data (2 LCA experts – 30 days; 3 workers – 5 days; 1 programmer – 20 days)	4.750
	Construction of LCA database server and test (2 LCA experts, 1 worker and 1 programmer – 10 days)	2.000
Life cycle assessment	LCA execution	0.306 [a]
Total (M/M)		**15.606**

[a] The value of M/M comes from the result of the fifth column in Table 5.

as 17.963. The most time consuming work is the data collection using questionnaires, requiring 5.5 M/M. This value is relatively high as the data collection has been carried out for the whole products in the two iron and steel work sites. But it may take much more time for field workers to fill out questionnaires under instructions, since they are not LCA experts. When we conducted the first phase of the LCA project by the manual entry method four years ago, all the data were made up manually through annual reports and other documents. At that time, ERP didn't exist. Furthermore, it was impossible for us to receive data directly from the legacy system, because of the lack of confidence in the data quality and the company policy. Only a little data could be received from ESS and EMS. Therefore, most of the LCA data was obtained manually using questionnaires. To save these kinds of unnecessary manpower, we attempted to link LCA S/W to ERP and other database systems for automatic data gathering. **Table 3** and **4** show the man-months consumed to execute LCA that was interfaced with the ERP system alone and with ERP plus other database servers, respectively. Most of the time was devoted to developing and setting up the interface programs. Interfacing with the ERP alone (Table 3) requires more M/M than interfacing with the other ERP plus database systems (Table 4), because an extra time is needed to set up an additional environmental module in the ERP alone system. There does not seem to be much difference in M/M for the first phase of LCA execution between the manual entry and on-line data gathering methods.

However, once the programs are set up for the execution of the first phase of LCA, there is a big improvement for the next normal phase of LCA execution with the on-line data gathering methods. **Table 5** shows results of the LCA execution at the normal phase (a repetitive and steady state of LCA performance excluding the first phase of LCA execution as shown in Table 2–4) for the three different data collecting methods. For the manual entry method, most execution steps at the normal phase require much smaller amount of time than those at the first phase, for example the data collection step. 5.5 M/M for the data collection during the first phase (Table 2) can be reduced to 50% (2.75 M/M in Table 5) for the normal phase. For the data collection in the normal phase, we used the same form of the questionnaires that was used in the first phase. For the on-line interface methods, no additional works are required in the steps of the data collection and evaluation at the normal phase since the data is automatically logged in from the database systems using the interface program. Moreover, there has been nearly no change of process in the steel works. Therefore,

Table 5: Comparison of M/M for LCA execution at the normal phase

LCA Phases	Description	Manual Entry (M/M)	ERP only Interface (M/M)	Integrated Interface (M/M)
Goal & scope definition	Goal & scope definition (1 LCA expert – 1 hour)	0.006	0.006	0.006
Life cycle inventory analysis	Data collection using questionnaires (1 worker per 110 unit processes – 4 hours)	2.750	0.000	0.000
	Validation of collected data (1 LCA expert – 2 hours per unit process)	1.375	0.000	0.000
	Confirmation of revised data (1 worker per 110 unit processes – 1 hour)	0.688	0.000	0.000
	Completion of missing data by calculation or literature survey (1 LCA expert – 1/2 hour per 110 unit processes)	0.344	0.000	0.000
	Conversion of data format and insertion data to LCA S/W (1 LCA expert – 2 days)	0.100	0.000	0.000
	LCI analysis and review (1 LCA expert – 2 days)	0.100	0.100	0.100
Life cycle impact assessment	Life cycle impact assessment (1 LCA expert – 1 day)	0.050	0.050	0.050
Life cycle interpretation	Life cycle interpretation (1 LCA expert – 3 days)	0.150	0.150	0.150
Total (M/M)		**5.563**	**0.306**	**0.306**

once data is checked for the first phase, there is no additional effort required during the next normal phase for evaluating transferred data and checking the lack of data.

Table 6 shows the results of M/M required for executing an LCA when there is variation in the process. New processes such as COREX, FINEX, TWB, etc. have been introduced recently in the steel industry. COREX and FINEX are new factories substituting a BF (blast furnace) process. TWB (Tailor Welded Blank) is the latest process to make steel sheet for automobiles. If these kinds of new processes are introduced, the process tree and mapping table, etc. should be modified, requiring additional M/M for subsequent modification of interface program. From the table, it can be seen that the on-line data gathering is more efficient than the manual data entry by about 9-fold. Using the on-line system, it is possible for us to perform LCAs more frequently every year or every month. Moreover, in the integrated interface system LCA manager can also handle the LCI methodologies such as allocation, assumptions, etc. If this system is expanded to environmental management of the whole enterprise, lots of benefit can be brought to the company in economic and social aspects.

Table 6: Comparison of M/M for LCA execution at the variation of a process

LCA Phases	Description	Manual Entry (M/M)	ERP only Interface (M/M)	Integrated Interface (M/M)
Goal & scope definition	Goal & scope definition (1 LCA expert – 1 hour)	0.006	0.006	0.006
Life cycle inventory analysis	Modification of process tree and questionnaire (1 LCA expert and 1 worker – 1 day)	0.100	0.000	0.000
	Data collection using questionnaires (1 worker per 110 unit processes – 4 hours)	2.750	0.000	0.000
	Validation of collected data (1 LCA expert – 2 hours per unit process)	1.375	0.000	0.000
	Confirmation of revised data (1 worker per 110 unit processes – 1 hour)	0.688	0.000	0.000
	Completion of missing data by calculation or literature survey (1 LCA expert – 1/2 hour per 110 unit processes)	0.344	0.000	0.000
	Conversion of data format and insertion data to LCA S/W (1 LCA expert – 2 days)	0.100	0.000	0.000
	Modification of mapping table and process trees (1 LCA expert, 1 worker and 1 programmer – 1 day)	0.000	0.150	0.150
	Modification of query sentences for interface change (1 LCA expert and programmer – 4 hours)	0.000	0.050	0.050
	Cross check between on-line data and off-line data (1 LCA expert and 1 programmer – 1 day)	0.000	0.100	0.100
	LCI analysis and review (1 LCA expert – 2 days)	0.100	0.100	0.100
Life cycle impact assessment	Life cycle impact assessment (1 LCA expert – 1 day)	0.050	0.050	0.050
Life cycle interpretation	Life cycle interpretation (1 LCA expert – 3 days)	0.150	0.150	0.150
Total (M/M)		**5.663**	**0.606**	**0.606**

3.3 Interface program and completion of LCA database server

A whole scheme related to this LCA S/W package including interface program is expressed in **Fig. 1**. Interface program links LCA database server (LCA DB) with three database systems (ERP/EMS/ESS) for on-line data collection. Data that are interfaced from the database systems are stored in the interfaced data section of the LCA DB. Among this data, flow values are stored at the project table through a one-to-one correspondence. The project table is composed of 4 sub-tables, which are article, module/unit/distributor, flow and connection. In the case of the blast furnace (BF) process, for example, the articles are iron ore, coke, lime, hot metal, and so on. The name of the module is BF and ten units exist within it, which are No 1-BF, No 2-BF, No 3-BF, No 1-BF wastewater treatment, etc. Flow means the quantity of the article. That is, the flow value of iron ore in No 1-BF is 412,970 ton. The BF process is connected to a distributor having various mathematical relations. The distributor is a functional tool to perform LCAs continuously for the diverse steel products. We define variable and yield for each process. Yield is defined as the ratio of the quantity of main input and of the main output in a process. Project name list also exists as a table in LCA DB. LCA DB is completed by interfacing data from three different systems. Data of raw materials, ancillary materials, products and by-products are interfaced from the ERP and the ESS through the legacy system. Energy-related data including utilities (by-product gases, heavy fuel oil, steam, electricity, oxygen, water, etc.) are also interfaced from the ESS. From EMS, we receive information in relation to air, water emissions and solid wastes. The terminology for articles used in the LCA DB was a little different from that in the database systems. Therefore, we used standardized names of articles that were based on the terms of International Iron and Steel Institute (IISI). In the case that a terminology could not be found in IISI, we adopted the terminology that has been used in actual fields. Many trials and errors were repeated to check any errors in items and values of articles in the LCA DB after comparing with manually completed DB with supervision from the field experts.

The LCA DB contains only actual data information in a process such as the name of substance, the location of article, and its quantity, excluding LCA execution results. Using this tool, we can construct LCA DB of on-site data for all the processes. All the in-house process data is interfaced periodically. Whenever a LCA manager operates the LCA program, project tables are generated automatically and LCA can be executed at the client/server mode. The execution results can be stored within his client personal computer not in the LCA DB.

4 Case Study for a Steel Product: Realization of LCA through On-line Data Collection

An LCA project manager gets all the data for LCA execution by running the interface program in his personal computer every month, quarter or half-year. The interfaced data are stored in the LCA DB. Every LCA practitioner can enter the LCA DB in his client computer and perform an LCA using LCA software. The goal of the present case study is to compare LCI and LCIA results of a steel product of slab, between the manual and automatic data gathering method. One ton of slab at the factory gate was used as the functional unit in this study. We analyzed the environmental impacts of slab from 'cradle to gate' on the basis of ISO 14040s. We also referred LCA methodologies to the report of the International Iron and Steel Institute (IISI 1998). Data sources were comprised of site data and upstream data. 'Site' refers to the iron & steel works boundary. It includes the data for all the manufacturing processes and utility plants within the works. We used upstream data made after mid-1990 named DEAM and accomplished around 2000 in Korea (KELA 2003). This has less reliability, geographical relevance, methodology and completeness compared to data collected from in-house processes.

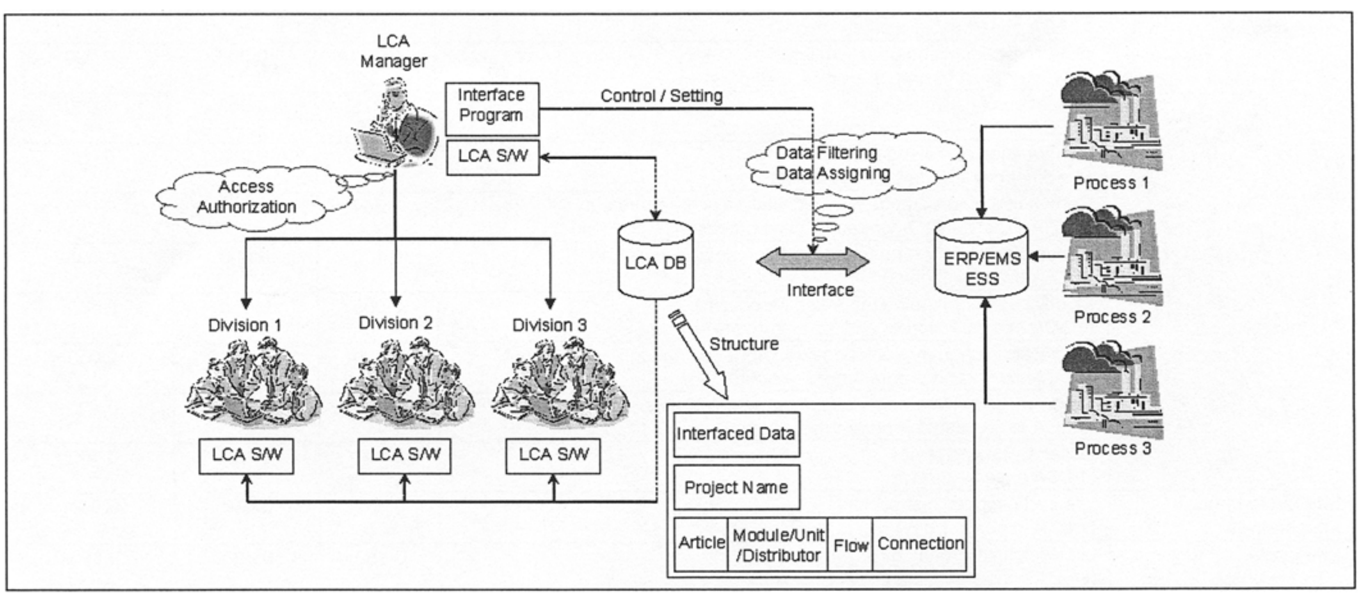

Fig. 1: A whole scheme related to LCA S/W package linkage with ERP/EMS/ESS and interface to LCA software

4.1 Steel-making Process

The target of the LCA study is a steel-making process in the iron & steel works. Within the scope of this research, the system functions can be all the steel products, including intermediate and final products, but in this paper we select slab among them. **Fig. 2** shows a series of processes for slab manufacturing. The product manufacturing system is comprised of the extraction of raw materials, their transportation to the works, utility production including electricity generation and production processes of steel products. The steelmaking process is mainly composed of three processes: iron-making, steel-making, and rolling. Iron-making is a process comprised of material treatment, sintering, lime calcining, coke baking, and smelting. Iron ore and coke are deposited into the top of a blast furnace. Super-heated blast air (1,200 °C) is fed from the lower part of the 100 m tall furnace. This causes the coke to burn at an extremely hot temperature, causing the iron ore to be melted. In the steelmaking process, the molten iron is poured together with steel scraps and limestone into an oxygen converter. Pure oxygen is injected into the iron, oxidizing the impurities and refining the steel. The molten steel is immediately fed through a continuous casting machine, producing semi-finished products such as slab or bloom. The semi-finished slab or bloom is reheated and fed through a variety of rolling mills to make one of many 'finished' products, including hot rolled coil, steel plate, or wire rod.

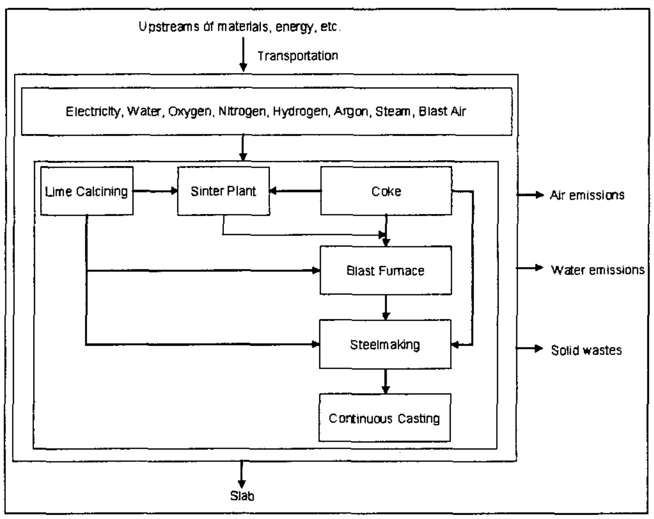

Fig. 2: A simplified schematic process tree and system boundary for LCA of slab in iron & steel works

4.2 Life cycle inventory (LCI) analysis of slab by manual and automatic method

We conducted the life cycle inventory of slab and the results are shown in **Fig. 3**. LCI executed by the manual method for the period of one year shows about 1296 kg/ton of slab for the emission of carbon dioxide (CO_2) to air. This value is about the same as the CO_2 value that was averaged for 12 times LCI done at the same period by the on-line data gathering through integrated interface. The automatic mode provides with more detailed data of LCI results by monthly basis, whose value varies from 1267 kg/ton to 1329 kg/ton of slab with 19 kg/ton of standard deviation. The monthly fluctuation of the CO_2 value is probably caused by a change in the amount and kind of fuel consumed in the slab making processes.

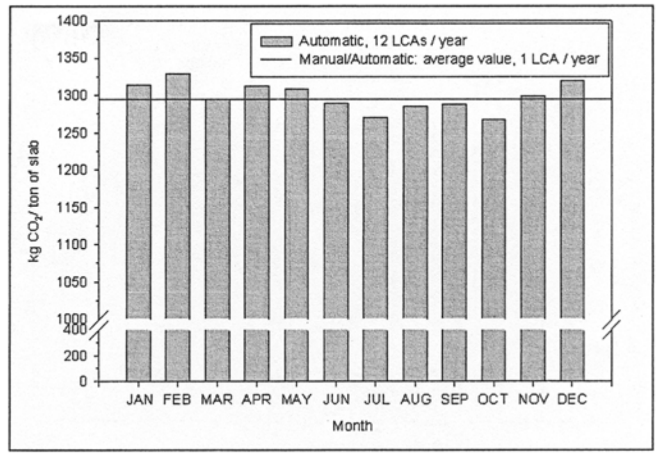

Fig. 3: Carbon dioxide (CO2) variation in the LCI of slab for two interface methods (manual and automatic)

Fuels in the steel industry are comprised of by-product gases and imported energy sources. Among by-product gases, blast furnace gas (BFG) and basic oxygen furnace gas (BOF gas) have very high values of the carbon dioxide emission factor (CEF). The CO_2 emission factors of the above two gases are about 267 g-CO_2/MJ and 193 g-CO_2/MJ, respectively. The CEF of coke oven gas (COG) is very low (45 g-CO_2/MJ). Liquefied natural gas (LNG), liquid petroleum gas (LPG) and heavy fuel oil (HFO) also have values lower than 80 g-CO_2/MJ. Thus, the CO_2 emission factors of COG and LNG are roughly 1/6 and 1/5 of that of BFG, respectively. In addition to the quantity of fuels consumed, we can detect the amount of by-product gases produced such as BFG, COG and BOF gas. BFG is used as an energy source in power plants, steam plants, blast furnaces, coke ovens, etc. COG is also used as one in power plants, steam plants, blast furnaces, coke ovens, basic oxygen furnaces, continuous casters, hot rolled mills, cold rolled mills, and so on. BOF gas is just used in power plants. These process gases are very important fuel in the integrated steel works. By-product gases are allocated to coal in IISI methodology by system expansion method. We also tested four types of alternative energy sources, which are coal, heavy fuel oil, LPG and LNG, in the sensitivity analysis for applying the method to our system. Coal substitution showed the best result among them. From the LCA study point of view, the use of cleaner energy such as COG can reduce CO_2 emission in life cycle inventory analysis due to its low CEF as COG. Also, clean fuel that is used in a more down-stream process is more environmentally friendly.

4.3 Life cycle impact assessment (LCIA) of slab by manual and automatic method

Nowadays, a hot issue in steel industry is the greenhouse problem, because steel companies emit the largest amount of CO_2 among industries. Greenhouse gases such as carbon dioxide or methane cause a slow rise in global temperature. As seen in **Fig. 4**, the global warming potential (GWP) is about 1303 kg eq. CO_2/ton of slab from the LCIA done by manual LCA method. From the LCIA by on-line data gathering through integrated interface, we obtained 12 monthly values ranging from 1276 kg eq. CO_2/ton to 1334 kg eq. CO_2/ton of slab with 18 kg eq. CO_2/ton of standard devia-

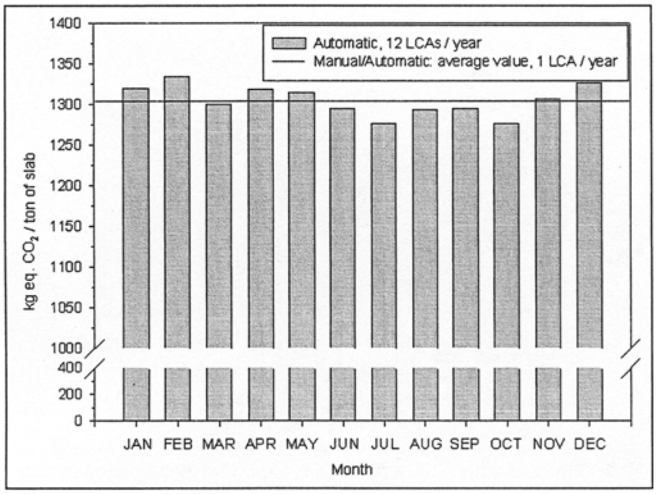

Fig. 4: Life cycle impact assessment for slab [IPCC: Greenhouse effect (direct, 100 years)]

tion. The standard deviation in LCIA is similar to that of CO_2 in LCI results. This is because, in the steel company, the largest contribution to GWP is CO_2. Other gases such as methane (CH_4) and nitrous oxide (N_2O) have less contribution, although these gases have much higher GWP factors than CO_2, that is 21 times and 310-fold, respectively.

5 Conclusions

Life cycle assessment (LCA) can be performed automatically through on-line data gathering after linking all the data necessary for LCA execution to a variety of enterprise database systems. Only raw data are automatically interfaced and stored to the LCA DB. Database systems include enterprise resource planning (ERP) and auxiliary systems such as the environmental management system (EMS) and energy server system (ESS). An LCA database server has been developed to link between the existing LCA software package and the database systems after matching all the LCA data with the necessary data that is located in different database systems using a one-to-one mapping technique. Through the practical application to the iron & steel works, we have shown that on-line method by integrated data interface is superior to the manual data gathering in terms of time & cost (man-month) saving, data reliability and a broad range of use over departments/sections. And monthly on-line data calculations of steel products have shown fluctuations probably due to fuel usage ratio in the results of LCI and LCIA.

6 Perspective

From now on, an enterprise should perform environmental management to survive in the global market, because environment will be a great trade barrier in the near future. Consumers will buy environmentally friendly products if possible. For environmental management, an enterprise complies with ISO 14000s. As we describe at the beginning of this article, LCA is in the center of the environmental management model. Some people have tried to apply LCA to environmental management (Sarkis 1998, Lee and Park 2001, Ross and Evans 2002). Integrating economic analysis into LCA is a good attempt for environmental management (Rosenblum et al. 2000, Norris 2001). To go ahead of this situation, a fast and accurate analysis of LCA is indispensable. The realization of LCA through on-line data collection, after linking LCA S/W with various enterprise database systems, is an exact answer.

The construction of the LCA DB is inevitable for environmental management of an enterprise. On-line analysis of environmental assessment for a product or process enables the enterprise to save time and cost. The LCA results will be used to formulate programs for systematic improvement of the company's environmental protection efforts. This system enables an enterprise to take Type III (Eco-labeling) and conduct benchmarking to other companies or societies in a short time. In the near future, combining this tool with Environmental Performance Evaluation (EPE) or accounting system, more progressive environmental management can be achieved.

Acknowledgement. This work was financially supported by POSCO. The authors thank many staffs of POSCO related to this project and programmers of Fireworks Co. We are also grateful for partial financial support from the Ministry of Education of Korea through the BK21 project.

References

CML (2001): Life Cycle Assessment – An Operational Guide to the ISO Standards (Final Report). Centre of Environmental Science, Leiden, The Netherlands

Heijungs R, Guinée JB (1995): On the Usefulness of Life Cycle Assessment of Packaging. Environmental Management 19 (5) 665–668

IISI (1998): Worldwide LCI Database for Steel Industry Products-Technical Report #1. International Iron and Steel Institute, Brussels, Belgium

ISO 14040 (1997): Environmental Management – Life Cycle Assessment – Principles and Framework

ISO 14041 (1998): Environmental Management – Life Cycle Assessment – Goal and Scope Definition and Inventory Analysis

ISO 14042 (1999): Environmental Management – Life Cycle Assessment – Life Cycle Impact Assessment

ISO 14043 (2000): Environmental Management – Life Cycle Assessment – Life Cycle Interpretation

Januschkowetz A, Hendrickson CT, Garrett JH (2000): Models for Combining Enterprise Resource Planning Systems and Life Cycle Assessment Software. The Fourth International Conference on Ecobalance, Tsukuba, Japan, 185–188

Klöpffer W (1997): Life Cycle Assessment. ESPR – Environ Sci & Pollut Res 4 (4) 223–228

Korea Environmental Labeling Association (KELA) (2003): LCI D/B List. http://www.kela.or.kr/korean

Korea ERP Association (KERP21) (2002): ERP Study. http://www.erp21.com

Lee KM, Park PJ (2001): Application of Life Cycle Assessment to Type III Environmental Declarations. Environmental Management 28 (4) 533–546

NEC (2001): The NEC Annual Environmental Report, Japan

Norris GA (2001): Integrating Life Cycle Cost Analysis and LCA. Int J LCA 6 (2) 118–120

Posch A (2001): STABIS – An Integrated Environmental Management Tool. The Inaugural Meeting for the International Society for Industrial Ecology (ISIE), The Netherlands

POSTECH (2002): Upgrade of LCI/POEM S/W, Linking with PI and Development of LCA Application Module. Report 2001Y206, Pohang University of Science and Technology, Pohang, Korea

Rosenblum J, Horvath A, Hendrickson CT (2000): Environmental Implications of Service Industries. Environmental Science & Technology 34 (22) 4669–4676

Ross S, Evans D (2002): Use of Life Cycle Assessment in Environmental Management. Environmental Management 29 (1) 132–142

Sarkis J (1998): Evaluating Environmentally Conscious Business Practices. European Journal of Operational Research 107 (1) 159–174

Suh IS, Chung KS, Park JI, Eun JH, Chung JS (2000): Development of Client/Server Version of LCA Software 'POEM'. The Fourth International Conference on Ecobalance, Tsukuba, Japan, 697–698

Received: January 27th, 2003
Accepted: June 2nd, 2003
OnlineFirst: June 4th, 2003